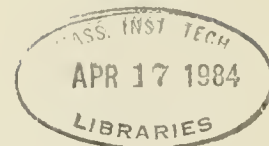WORKING PAPER
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Exchange Rate Dynamics with Sticky Prices:
The Deutsch Mark, 1974-1982

by

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and
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EXCHANGE RATE DYNAMICS WITH STICKY PRICES:

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Abstract

This paper estimates simultaneously dynamic equations for the
Deutsche Mark/Dollar exchange rate and the German wholesale price index,
which emerge from a model in which German prices are sticky. This
stickiness is due to costs of adjusting prices of the form posited by
Rotemberg (1982).

The main results of the empirical analysis are two: First, the
version of the model where prices are perfectly flexible is rejected.
Second, real exchange rate variability is mostly accounted for by nominal
exchange rate variability. We find substantial overshooting of the
exchange rate to monetary innovations like those which appear to by
typical in Germany.

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1. Introduction

The idea that purchasing power parity holds with flexible exchange rates at every moment in time has been shown by the data since 1974 to be wrong. Real exchange rates are not constant, and, moreover, their changes tend to persist (see Frenkel (1981)). Also, nominal exchange rates fluctuate much more than price indices. One possible explanation for these phenomena, which is advanced in Dornbusch (1976), is that the prices of goods produced for the domestic market change slowly. Then, in his deterministic model, a once and for all increase in money leads to an instantaneous depreciation which "overshoots" the new steady state exchange rate. Afterwards, the price level slowly increases and the

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exchange rate appreciates. Our paper attempts to estimate a model of this type on German data since 1974. We too assume that prices move slowly. On the other hand, our paper differs in important respects both from Dornbusch's original formulation and from its empirical implementation by Frankel (1979) and Driskill and Sheffrin (1981).

First, we consider also the impact of nonmonetary variables both on steady states and on the paths of price levels and exchange rates. In particular we focus on the effect of changes in prices of various imported goods and on changes in real wages. The latter's effect on exchange rates has been the focus of work Sachs (1980) among others.

Second, our specification of the stickyness of prices relies on explicit costs of price adjustment on the part of firms. These costs of price adjustment are akin to those in Rotemberg (1982a) and attempt to capture the fear on the part of firms that customers will desert them if they follow erratic pricing policies.

Finally, we do not impose the assumption that money is a random walk. This is simply false for Germany as is noted by Driskill and Sheffrin (1981). Hence the response of exchange rates and prices to monetary shocks differs from the responses considered by Dornbusch (1976) and his followers. So, we let the data inform us as to the plausible stochastic processes followed by the forcing variables we consider. Then we assume that exchange rates and prices respond optimally in that private agents are assumed to also know the stochastic processes of the forcing variables.

While we feel that these differences constitute important improvements over previous work we must point out at the outset some important caveats. First, the period since 1974 is only partially a

period of "flexible" exchange rates between Germany and the rest of the world which we aggregate into a dollar region. This is so because within Europe exchange rates are only allowed to move within bands. So, whether flexible exchange rate models can explain DM exchange rates is an empirical question. Second, from the theoretical point of view our model fails to explicitly take into account the intertemporal budget constraint that makes the present value of current account deficits equal to the current stock of net foreign assets. Unfortunately, explicit use of the budget constraint appears at the present time to lead to models too complicated for estimation. Instead, we assume, as is standard practice in empirical exchange rate models, that there is perfect asset substitutability: that is that the expected yield in domestic currency of investing at home and abroad is the same. We do this also for tractability, since the specification of imperfect substitutability models is econometrically difficult. Moreover, the assumption perfect substitutability, while statistically rejected by several authors, could be a reasonable approximation of the data.

The structure of the paper is as follows. Section 2 presents the model and its solution, Section 3 estimates the model using German data, for the period from June 1974 to February 1983. Section 4 presents simulations of the responses of the endogenous variables to a variety of shocks, under the rational expectations assumption. Finally, Section 5 contains some concluding remarks. The appendices describe the solution of the model and the data used in the empirical section.

2. The Model

Our economy is populated by a large number of monopolistically competitive firms, each producing a good that is differentiated from other domestic goods, and from foreign goods. Each firm faces the following demand curve for its product:

$$(1) \qquad Q_{it} = \left(\frac{P_{it}}{P_{dt}^{\lambda}(E_t P_{ct}^*)^{1-\lambda}}\right)^{-\gamma} \left(\frac{M_t}{P_{dt}^{\lambda}(E_t P_{ct}^*)^{1-\lambda}}\right)^{d} Q_t^{*f} N_{1t}$$

where Q_{it} is demand for good i at time t. The first term in the right hand side of (1) represents substitution between domestic and foreign goods, and captures substitution both by domestic residents and by foreigners. P_{dt} is the index of domestic goods prices, a geometrically weighted average of P_{it}'s. P_{ct}^* is the price of foreign consumption goods, taken as exogenous. This implies that although our country is "small," each domestic producer does not face a perfectly elastic demand schedule by foreign residents. The second term on the right hand side of (1) represents a real balance effect on domestic demand, Q_t^* stands for foreign activity, and N_{1t} is a random variable which affects demand for goods.[1]

On the cost side, we assume that all domestic goods, together with imported intermediates and labor are used in the production of each good i. Marginal costs of production of good i is:[2]

$$(2) \qquad Q_{it}^{\beta} \, P_{dt}^{(1-\alpha_1-\alpha_2)} \, W_t^{\alpha_1} (E_t P_{Nt}^*)^{\alpha_2} N_{2t}$$

with W_t the nominal wage rate, P_{Nt}^* the foreign currency price of imported

intermediate goods, and N_{2t} is a random variable affecting productivity. When $\beta = 0$ we have the constant variable costs case.

Real wages relative to the CPI are given by:

(3)
$$\dot{W}_t = K_t P_{dt}^{\lambda} (E_t P_{ct}^{*})^{1-\lambda}$$

where K_t is the real consumption wage at time t. K_t is assumed to be exogenous throughout the paper. This assumption is consistent with recent empirical findings (von Jurgen (1982)).

Domestic producers are assumed to observe M, P_c^{*}, P_N^{*}, Q^{*}, E and K at the time of their pricing decision: price setting is synchronized.

In the absence of costs of changing prices, domestic producers would charge $\bar{P}_{it}$, at which marginal cost equals marginal revenue. In natural logarithms, it is equal to

(4)
$$\bar{P}_{it} = \frac{1}{1+\beta\gamma} \{ [\beta\lambda(\gamma - d) + 1 - \alpha_1 - \alpha_2 - \lambda\alpha_1]p_{dt} + [\beta(1 - \lambda)(\gamma - d) \\ + (1 - \lambda)\alpha_1 + \alpha_2]e_t + [\beta(1 - \lambda)(\gamma - d) + (1 - \lambda)\alpha_1]p_{ct}^{*} \\ + \alpha_2 p_{Nt}^{*} + \alpha_1 k_t + \beta dm_t + \beta f q_t^{*} + n_t \}$$

where lowercase letters are the logs of the variables represented by the corresponding uppercase letters, and $n_t = n_{2t} + \beta n_{1t}$.

However, we follow Rotemberg (1982a) by assuming that monopolists also have convex costs of changing nominal prices. They are assumed to solve the following problem:

(5)
$$\text{Max } E_t \sum_{j=0}^{\infty} \rho^j [\pi(\bar{P}_{it+j}) - \bar{w}_i(p_{it+j} - \bar{P}_{it+j})^2 - c_i(p_{it+j} - p_{it+j-1})^2]$$

where ρ stands for a constant discount factor, and E_t is the expectations operator, conditional on information available at time t. The first two terms in the square bracket represent a second order approximation around $\bar{p}_{it}$, of the profit function of producer i in the absence of costs of changing prices;[3] the third term represents the decrease in current profits to be accounted for by price changes. Setting $c_i/\bar{w}_i = c$, for every i, we have the final expression of the domestic producers' objective function:

$$(6) \qquad \text{Min } E_t \sum_{j=0}^{\infty} \rho^j [(p_{it+j} - \bar{p}_{it+j})^2 + c(p_{it+j} - p_{it+j-1})^2]$$

Solution of the problem in (6) leads to the equation describing equilibrium price dynamics for each domestic producer:

$$(7) \qquad {}_tp_{it+1} - (\frac{1 + c + \rho c}{\rho c}) \, p_{it} + \frac{1}{\rho} \, p_{it-1} = -\frac{1}{\rho c} \, \bar{p}_{it}$$

where for every variable x, ${}_tx_{t+j}$ indicates the expectations of x at time t+j, conditional on information available at time t. Equation (7) can now be aggregated to obtain the equilibrium dynamics of the domestic price level:

$$(8) \qquad {}_tp_{dt+1} - \frac{1}{\rho c} [1 + c + \rho c - \frac{\beta\lambda(\gamma - d) - \alpha_1(1 - \lambda) + 1 - \alpha_2}{(1 + \beta\gamma)}] p_{dt}$$

$$+ \frac{1}{\rho} \, p_{dt-1} = -\frac{1}{\rho c(1 + \beta\gamma)} \{[\beta(1 - \lambda)(\gamma - d) + (1 - \lambda)\alpha_1 + \alpha_2]e_t$$

$$+ [\beta(1 - \lambda)(\gamma - d) + (1 - \lambda)\alpha_1]p_{ct}^* + \alpha_2 p_{Nt}^* + \alpha_1 k_t + \beta dm_t + \beta fq_t^* + n_t\}$$

under the assumption that exogenous variables in (8) are of exponential order less than $1/\rho$, it can be shown that equation (8) has one stable

and one unstable root and that in this case there exists a unique stable path that leads to the steady state (Blanchard and Khan (1980)). The domestic price level is a function of all future values of exogenous variables, which for domestic producers include m, p_c^*, p_N^*, q^*, k, e and n.

The model is closed with the specification of asset markets equilibrium. Domestic and foreign bonds are assumed to be perfect substitutes. Therefore, the ex-ante real interest differential is zero:

$$(9) \qquad\qquad {}_te_{t+1} - e_t = i_t - i_t^*$$

where i_t and i_t^* are the domestic and foreign interest rate, respectively. Finally, we have the money demand equation:

$$(10) \qquad\qquad m_t - \lambda p_{dt} - (1 - \lambda)(e_t + p_{ct}^*) = aq_t - bi_t + n_{3t}$$

where n_{3t} is a random variable affecting velocity. In order to obtain the dynamics of the exchange rate, we need assumptions about equilibrium output. The hypothesis is that domestic firms are never rationed in the labor market, and intermediate goods market, and supply whatever quantity of the good they produce is demanded. In this case, equilibrium domestic output is given by aggregating (1):

$$(11) \quad q_t = (e_t + p_{ct}^*)(\gamma - d)(1 - \lambda) - [\gamma - (\gamma - d)\lambda]p_{dt} + fq_t^* + dm_t + n_{1t}$$

the dynamics of the exchange rate are obtained by substituting (11) into money demand, and using the relation (9):

(12) $\quad _te_{t+1} - e_t[1 + (\frac{1 - \lambda}{b})(1 + a(\gamma - d))] - p_{dt}[\frac{\lambda}{b} - \frac{a}{b}(\gamma - (\gamma - d)\lambda)]$

$$= (\frac{ad - 1}{b})m_t + p_{ct}^*(\frac{1 - \lambda}{b})(1 + a(\gamma - d)) - i_t^* + \frac{af}{b}q_t^* + \tilde{n}_t$$

where $\tilde{n}_t = an_{1t}/b + n_{3t}$.

This completes the specification of the model. In matrix form, the two equations describing the dynamics of the economy can be written as follows:

(14) $\qquad\qquad\qquad\qquad _ty_{t+1} = Ay_t + Bz_t$

where:

$$y_t = \begin{bmatrix} p_{t-1} \\ p_t \\ e_t \end{bmatrix} \qquad\qquad z_t = \begin{bmatrix} p_{ct}^* \\ p_{Nt}^* \\ k_t \\ q_t^* \\ m_t \\ i_t^* \\ n_t \\ \tilde{n}_t \end{bmatrix}$$

$$A = \begin{bmatrix} 0 & & 1 \\ -\frac{1}{\rho} & \frac{1}{\rho c}[1 + c + \rho c - \dfrac{\beta\lambda(\gamma - d) - \alpha_1(1 - \lambda) + 1 - \alpha_2}{1 + \beta\gamma}] \\ 0 & & \frac{1}{b}[\lambda - a(\gamma - (\gamma - d)\lambda)] \end{bmatrix}$$

$$\begin{bmatrix} 0 \\ -\dfrac{[\beta(1 - \lambda)(\gamma - d) + (1 - \lambda)\alpha_1 + \alpha_2]}{\rho c(1 + \beta\gamma} \\ 1 + (\frac{1 - \lambda}{b})(1 + a(\gamma - d)] \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ -\dfrac{\beta(1-\lambda)(\gamma-d)+(1-d)+(1-\lambda)\alpha_1}{\rho c(1+\beta\gamma)}, \\ (\dfrac{1-\lambda}{b})(1+a(\gamma-d)), \end{bmatrix}$$

$$\begin{matrix} 0 & 0 \\ & -\dfrac{\alpha_2}{\rho c(1+\beta\gamma)} \\ & 0 \end{matrix}$$

$$\begin{matrix} 0 & 0 & 0 & 0 & 0 & 0 \\ -\dfrac{\alpha_1}{\rho c(1+\beta\gamma)}, & -\dfrac{\beta f}{\rho c(1+\beta\gamma)}, & -\dfrac{\beta d}{\rho c(1+\beta\gamma)} & 0 & -\dfrac{1}{\rho c(1+\beta\gamma)} & 0 \\ 0 & \dfrac{af}{b}, & \dfrac{ad-1}{b}, & -1 & 0 & 1 \end{matrix}$$

The solution of (14) is:

$$(16) \qquad p_{dt} = \omega_0 p_{dt-1} - (\frac{1}{J_{21}}) \sum_{j=0}^{8} \omega_{i1} [\sum_{k=0}^{\infty} (\frac{1}{J_{21}})^j {}_t z_{it+j}]$$

$$- (\frac{1}{J_{22}}) \sum_{i=1}^{8} \omega_{i2} [\sum_{j=0}^{\infty} (\frac{1}{J_{22}})^j {}_t z_{it+j}]$$

and

$$(17) \qquad e_t = \xi_0 p_{dt-1} - (\frac{1}{J_{22}}) \sum_{i=1}^{8} \xi_{i1} [\sum_{j=0}^{\infty} (\frac{1}{J_{22}})^j {}_t z_{it+j}]$$

$$- (\frac{1}{J_{22}}) \sum_{i=1}^{8} \xi_{i2} [\sum_{j=0}^{\infty} (\frac{1}{J_{22}})^j {}_t z_{it+j}]$$

where the ω's and the ξ's are listed in Appendix 1, J_{21} and J_{22} are the unstable roots of A and the z_i's are the elements of the z vector in (14).

Equations (16) and (17) indicate that the short run dynamics of the real exchange rate are indeed determined, among other things, by domestic price setters' expectations about the evolution of variables determining profits[4]. For example, given an anticipated future change in the price of imported intermediate goods, domestic producers would balance the loss

of abruptly changing prices when the increase in input costs comes by, with lower profits today, by partially increasing today's prices. Short run fluctuations of the real exchange rate are not exclusively due to financial disturbances (which would exclusively shift asset demands), although these shocks play a fundamental role here too. Furthermore, and more importantly, unanticipated nominal shocks do have significant real effects, as domestic producers are unwilling to instantaneously adjust output prices to the long run equilibrium level. In the long run, once and for all increases in the money stock can be shown to have no real effects.

Another important feature of short run equilibrium is that, although steady state employment is always increased by lowering the consumption wage, these policies are relatively ineffective in the short run. Domestic producers do not decrease the relative price of domestic goods instantaneously, thus giving rise to a short run increase in profits, with not expansionary effects. In this sense, short run unemployment can be considered "Keynesian."

3. Estimation

This section is divided in two parts. In subsection a) we present the estimates obtained from the Euler equations (8) and (12). Subsection b) presents the time series properties of the forcing variables q^*, i^*, p_C^*, p_N^*, m and k.

3.a. Exchange Rate and Domestic Price Level Euler Equations

The Euler equations we actually estimate are given by:[5]

(8')
$$E_t[\rho\hat{\phi}_3 p_{dt+1} - p_{dt} + \hat{\phi}_3 p_{dt-1} + (1 - (1 + \rho)\hat{\phi}_3 - \hat{\phi}_7)e_t$$

$$+ (1 - (1 + \rho)\hat{\phi}_3 - \hat{\phi}_7 - \hat{\alpha}_2)p_{ct}^* + \hat{\alpha}_1 k_t + \hat{\alpha}_2 p_{Nt}^* + \hat{\phi}_7 m_t + \hat{\phi}_6 q_t^* + n_t] = 0$$

(12')
$$E_t[e_{t+1} - (1 - \phi_1 - \phi_4)p_{dt} - \phi_1 e_t + (\phi_1 - 1)p_{ct}^*$$

$$- \phi_4 m_t - \phi_5 q_t^* - i_t^* + \tilde{n}_t] = 0.$$

where

$$\hat{\phi}_3 = (\frac{\phi_3}{(1 + \rho)\ \phi_3 + \phi_2 + \phi_7})$$

$$\hat{\phi}_7 = (\frac{\phi_7}{(1 + \rho)\ \phi_3 + \phi_2 + \phi_7})$$

$$\hat{\alpha}_1 = (\frac{\alpha_2}{(1 + \rho)\ \phi_3 + \phi_2 + \phi_7})$$

$$\hat{\alpha}_2 = (\frac{\alpha_2}{(1 + \rho)\ \phi_3 + \phi_2 + \phi_7})$$

$$\hat{\phi}_6 = (\frac{\phi_6}{(1 + \rho)\ \phi_3 + \phi_2 + \phi_2})$$

and the ϕ's are given in the Appendix. The price equation is slightly

different from (8) since, for estimation the equation must be

normalized. The normalization we choose has the advantage of making it

easy to test for the absence of costs of changing prices by testing

whether ϕ_3 is zero. Note, however, that without other a priori

restrictions it is not possible to recover all the ϕ's and the α's from

the $\hat{\phi}$'s and the $\hat{\alpha}$'s. We therefore also reestimate (8') and (12')

assuming that α_1 and α_2 are given by .25 and .11 respectively. These

values are those which are consistent with the estimates of Dramais

(1980). This, in addition to identifying D which is given by $(1 + \rho)\phi_3 +$

$\phi_2 + \phi_7$ (see Table 1), and thus all the ϕ's, also imposes an additional

constraint.

The residuals obtained when the expectations operators are

eliminated from the left hand side of (8') and (12') have a number of

interpretations. If technology, money demand and output demand were all

deterministic functions, then n_t and $\tilde{n}_t$ would be equal to zero. In this

case, these residuals would simply be due to innovations in the forcing

variables. That is they would be due to the revisions in expectations

that take place when q^*_{t+1}, k^*_{t+1}, i^*_{t+1}, p^*_{ct+1} and p^*_{Nt+1} are realized.

These residuals would thus be uncorrelated with any information available

at time t. This suggests as a natural estimator the instrumental

variables procedure of Hansen (1982) and Hansen and Singleton (1982). As

Hansen discusses, this procedure is simply three-stage least squares if

one is willing as we are to assume also that the residuals are

conditionally homoskedastic. This is a particularly reasonable

assumption in our case since our focus on short run fluctuations leads us

to estimate with previously detrended data. Hansen (1982) also derives a

portmanteau statistic J which permits the testing of the overidentifying

restrictions. Unfortunately we cannot seriously entertain the hypothesis

that the cost function and demand functions are deterministic. Thus n_t

and $\tilde{n}_t$ also form part of the residuals of (8') and (12').

Insofar as these residuals are independently identically distributed

they are presumably also uncorrelated with certain instruments available

at t. This would still allow us to use three stage least squares.

Another possibility is that the structural residuals of the cost and demand equations are serially correlated. Suppose that the residual in (8') is the sum of two components, ε_{1t} and n_t. The first, ε_{1t}, is the expectational revision. Then, suppose that n_t is given by $(\rho_1 n_{t-1} + u_{1t})$ where u_{1t} is independently identically distributed. Similarly the residual in (12') is given by $\varepsilon_{2t} + \tilde{n}_t$ where $\tilde{n}_t$ is $\rho_2 \tilde{n}_{t-1} + u_{2t}$. Quasi-differencing (8') and (12'):

$$\rho \hat{\phi}_3 (p_{dt+2} - \rho_1 p_{dt+1}) - (p_{dt+1} - \rho_1 p_{dt}) + [1 - (1+\rho)\hat{\phi}_3 - \hat{\phi}_7](e_{t+1} - \rho_1 e_t)$$

$$(8'') \quad + [1 - (1+\rho)\hat{\phi}_3 - \hat{\phi}_7 - \hat{\alpha}_2](p^{*}_{ct+1} - \rho_1 p^{*}_{ct}) + \hat{\alpha}_1 (k_{t+1} - \rho_1 k_t) + \hat{\alpha}_2 (p^{*}_{Nt+1} - \rho_1 p^{*}_{Nt})$$

$$+ \hat{\phi}_7 (m_{t+1} - \rho_1 m_t) + \hat{\phi}_6 (q^{*}_{t+1} - \rho_1 q^{*}_t) = \varepsilon_{1t+1} + u_{1t+1} - \rho_1 \varepsilon_{1t}$$

$$e_{t+2} - (\phi_1 + \rho_2) e_{t+1} + \rho_2 \phi_1 e_t - (1 - \phi_1 - \phi_4)(p_{dt+1} - \rho_2 p_{dt})$$

$$(12'') \quad + (\phi_1 - 1)(p^{*}_{ct+1} - \rho_2 p^{*}_{ct}) + \phi_4 (m_{t+1} - \rho_2 m_t) + \phi_5 (q^{*}_{t+1} - \rho_2 q^{*}_t)$$

$$+ \rho_2 i^{*}_t - i^{*}_{t+1} = \varepsilon_{2t+1} + u_{2t+1} - \rho_2 \varepsilon_{2t}$$

Clearly (8'') and (12'') can still be estimated by three stage least squares as long as only instruments available at t are used and the u_{1t}'s are uncorrelated with them. However, now the residuals have a moving average component.

The estimators are obtained by using two lags for p_d, e, p^{*}_c, p^{*}_N,, q^{*}, i^{*}, k and m as instruments and constraining ρ to be equal to the discount factor corresponding to 5 per cent per year. The monthly data which we use, from June 1974 to February 1983, is described in Appendix 2. The results are reported in Table 1. Column I shows the

estimates obtained from (8') and (12'). Column II shows estimates from the same equation when the α's are constrained. Column III represents the results obtained from (8") and (12"). Finally the last column presents estimates obtained by constraining the α's in (8") and (12"). In columns I and II, the coefficient estimates are essentially unchanged when we constrain the α's. Quasi-differencing improves the DW statistics of the exchange rate equation somewhat. When α's are fixed, however, the roots do not have the desired property that one is stable while the others are unstable. The estimates of column II do have this property so we use those in our simulations.

The estimates of ϕ_3 are substantively and significantly different from zero thus underlining the importance of the price dynamics captured by the costs of changing prices. This significance is undoubtedly due in part to the absence of purchasing power parity in the data. Most of the other coefficients also have the required signs. The exceptions are ϕ_5 and ϕ_6, the coefficients of q^*. They are insignificantly different from zero, but have the wrong sign. The sign of ϕ_4 is the sign of $(\frac{ad - 1}{b})$. Other studies (Goldfeld (1973), Rotemberg (1982b)) have found values of a and d below 1. This is consistent with the negative ϕ_4 reported in columns I and II.

Finally, it must be noted that the J statistic rejects the overidentifying restrictions imposed by (8') and (12'). This may well be due in part to our assumption of perfect substitutability between domestic and foreign assets. While this assumption may represent a good approximation, it has been statistically rejected by Hansen and Hodrick (1980) among others.

Table 1

Estimates from Equations (8'), (12'), (8") and (12").

Parameter	I	II	III	IV
$\hat{\phi}_3$	.498 (.007)	.497 (.007)	.523 (.037)	.499 (.034)
$\hat{\phi}_6$	-.0017 (.0053)	-.0003 (.0043)	.0085 (.033)	-.0024 (.006)
$\hat{\phi}_7$	.0011 (.0096)	.0012 (.0095)	-.0826 (.048)	.0037 (.014)
ϕ_1	.839 (.039)	.837 (.039)	.778 (.125)	.776 (.118)
ϕ_4	-.204 (.100)	-.204 (.100)	.074 (.262)	.053 (.278)
ϕ_5	-.061 (.083)	-.063 (.083)	-.206 (.283)	-.191 (.262)
$\hat{\alpha}_1$	.021 (.030)		.141 (.092)	
$\hat{\alpha}_2$	.0023 (.003)		.011 (.026)	
D		44.27 (55.81)		18.82 (24.03)
ρ_1			1.018 (.131)	.462 (.558)
ρ_2			.727 (.187)	.717 (.579)
Roots	.765	.762	.723	.771
	1.046±.0821i	1.047±.0821i	.986±.327i	.920,1.097
DW of price Eq.	2.71	2.72	2.96	2.92
DW of Exch. Eq.	.75	.75	2.08	2.05
J	45.96	45.93		

Standard Errors in parenthesis. Standard errors in columns III and IV are computed as described in footnote 6.

3.b. Time Series Properties of Exogenous Variables

In this subsection we explore the time series properties of the forcing variables in order to obtain simple forecasting equations. These simple forecasting equations can then be attributed to private agents. This allows us to compute the effects of innovations in the forcing variables on the paths of e and p_d.

First, we consider the vector autoregressions having as variables p_d, e, q^*, i^*, p_c^*, p_N^* and m. Using monthly data from the middle of 1974 to February 1983, one can accept at the 5% level the hypothesis that q^*, i^*, p_c^*, p_N^* are not caused in the Granger sense by any other variable against the hypothesis that they are caused by all the variables in the system. The level of money, however, is significantly influenced by the past values of other variables. We also considered a system in which money and interest rates are first differenced. Since this partially first differenced system is more consistent with univariate evidence presented below, it probably leads to more reliable tests of hypotheses. In this second system one can accept for each forcing variable that it is not caused by any other variable against the hypothesis that they are caused by all of them. These results obtain for vector autoregressions using four, five and six lags. This doesn't lead us to believe that these variables are, in fact, independent. It just means that, for forecasting purposes, univariate time series models of these variables are probably adequate. This conclusion is tempered somewhat by the fact that within the vector autoregressions certain individual variables appear significantly causally prior to other variables.

The two variables which we concentrate on, p_d and e, do not cause the forcing variables in any of the systems we consider. This is a

Table 2

Significance Levels for the Absence of Causality From X to
Y in Partially First Differenced Vector Autoregressions

	VARIABLE Y					
VARIABLE X	p_N^*	p_C^*	q^*	i^*	m	k
p_N^*	$--$	.73	.19	.74	.46	.58
p_C^*	.59	$--$	.22	.70	.15	.99
q^*	.47	.88	$--$	.65	.15	.59
i^*	.31	.92	.54	$--$	.001	.995
m	.004	.39	.49	.47	$--$	.76
k	.69	.76	.80	.99	.72	$--$
p_d	.30	.64	.64	.053	.36	.67
e	.98	.68	.65	.95	.47	.55

precondition for the applicability of the Hansen and Sargent (1980) formulae.

Table 2 presents the significance levels for the tests that the coefficients of variable x are zero in the regression explaining variable y. These significance levels are obtained from the partially firsts difference model with six lags. As can be seen, changes in money are significantly (at the 5% level) causally prior to changes in the prices of imported intermediates while changes in interest rates are significantly causally prior to changes in money. We neglect the former causal relation on a priori grounds while we focus specifically on the latter one. So, we attribute to the agents on section 2 univariate forecasting rules for q^*, k, p_c^*, p_N^* and i^*. Instead we assume they forecast m using also information on past interest rates.

We employ Box-Jenkins techniques to obtain parsimonious representations for the stochastic processes followed by these variables. Parsimony is essential here since the forecasting formula of Hansen and Sargent (1980) becomes very complex as one enriches the parametrization of these processes.

The application of these principles to monthly data from 1974:7 to 1983:2 lead us to an AR(2) for p_N^* which, when estimated by OLS gives:

$$p_{Nt}^* = 1.175 \; p_{Nt-1}^* - .222 \; p_{Nt-2} \qquad DW = 2.08$$
$$\quad\;\; (.095) \qquad\qquad (0.95) \qquad\qquad R^2 = .93$$

Similarly p_{ct}^* is also well forecasted by an AR(2):

$$p_{ct}^* = 1.247 \; p_{ct-1}^* - .283 \; p_{ct-2}^* \qquad DW = 2.03$$
$$\quad\;\; (.093) \qquad\qquad (.093) \qquad\qquad R^2 = .95$$

instead q^* is well explained by just one lag of itself so that:

$$q_t^* = .948 \; q_{t-1}^* \qquad\qquad \begin{array}{l} DW = 1.85 \\ R^2 = .91 \end{array}$$

univariate autoregressions of i^* (and m) have coefficients which sum to 1 suggesting the presence of a unit root. A parsimonious representation for the process followed by i^* is:

$$i^* - i_{t-1}^* = \underset{(.094)}{.325} \; (i_{t-1}^* - i_{t-2}^*) - \underset{(.094)}{.248} \; (i_{t-2}^* - i_{t-3}^*) \qquad \begin{array}{l} DW = 2.00 \\ R^2 = .12 \end{array}$$

The most parsimonious process for money which eliminates all significant serial correlations seems to be:

$$m_t - m_{t-1} = \underset{(.093)}{.064} \; (m_{t-1} - m_{t-2})$$

$$- \underset{(.097)}{.086} \; (m_{t-2} - m_{t-3}) + \underset{(.096)}{.378} \; (m_{t-3} - m_{t-4})$$

$$+ \underset{(.113)}{.068} \; (i_{t-1}^* - i_{t-2}^*) - \underset{(.118)}{.238} \; (i_{t-2}^* - i_{t-3}^*)$$

$$+ \underset{(.118)}{.023} \; (i_{t-3}^* - i_{t-4}^*) - \underset{(.113)}{.268} \; (i_{t-4}^* - i_{t-5}^*)$$

$$DW = 2.00$$
$$R^2 = .21$$

Finally, the real wage k is well forecasted by an AR(3):

$$k_t = \underset{(.096)}{.294} \; k_{t-1} + \underset{(.097)}{.194} \; k_{t-2} + \underset{(.092)}{.164} \; k_{t-3} \qquad \begin{array}{l} DW = 2.06 \\ R^2 = .27 \end{array}$$

4.   Simulations

In this section, we use the estimates of the parameters of the
model presented in the previous section to simulate responses of the
price level and the exchange rate to a variety of shocks.

In the simulations, we substitute the estimates obtained from Euler
equations into the solution of the model, equations (16) and (17).
Furthermore, we apply the Wiener Kolmogorov prediction formulae as in
Hansen and Sargent (1980) to express the infinite summations in (16) and
(17) in terms only of present and past realizations of the exogenous
variables, using the estimates of the autoregressive parameters of these
variables.

These simulations differ from simulations of rational expectations
models as for example in Lipton and Sachs (1980), in that we specify a
realistic process followed by exogenous variables, rather than implicitly
assuming a random walk. Given our estimates, unanticipated shocks have
some persistence. Some of the shocks, however, eventually fade away.
By describing the effects of innovations in the processes governing the
exogenous variables, we perform an exercise similar to impulse responses
in vector autoregressive models. However, these simulations differ from
impulse responses as all the cross equation restrictions arising
from the rational expectations hypothesis are imposed here. These
restrictions are bound to improve the efficiency of the forecasts under
the rational expectations assumption. In this sense our simulations can
be thought as constrained impulse responses.

Figures 1 to 4 illustrate the effects of a unit increase in the
stock of money. Starting from steady state (all endogenous and
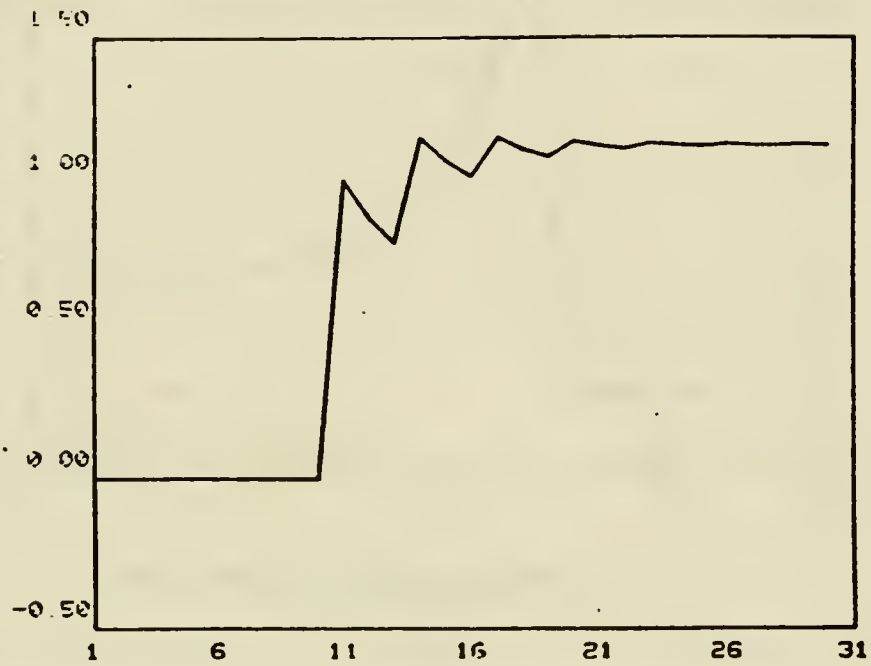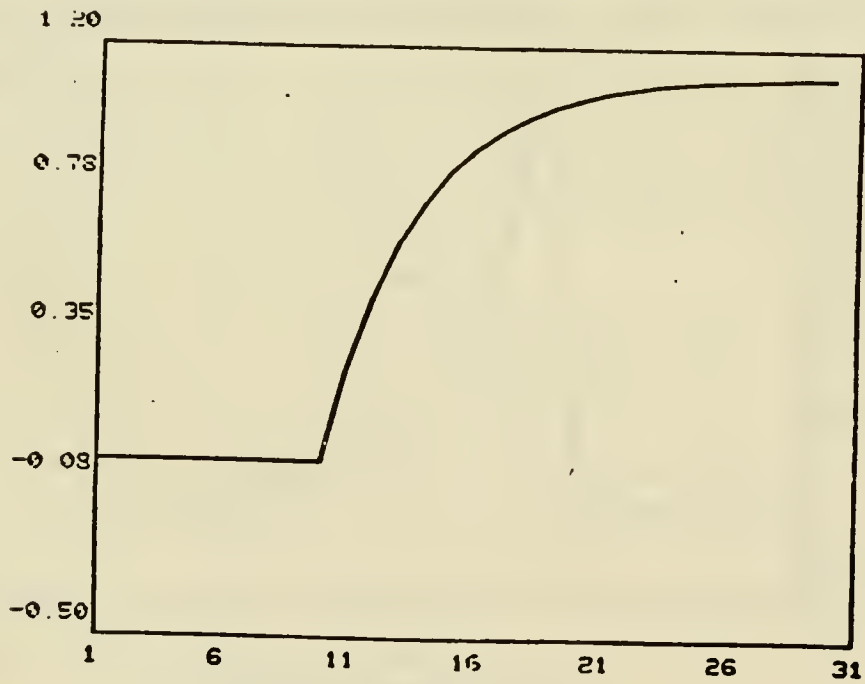
Figure 1: Money

Figure 2: Domestic Prices
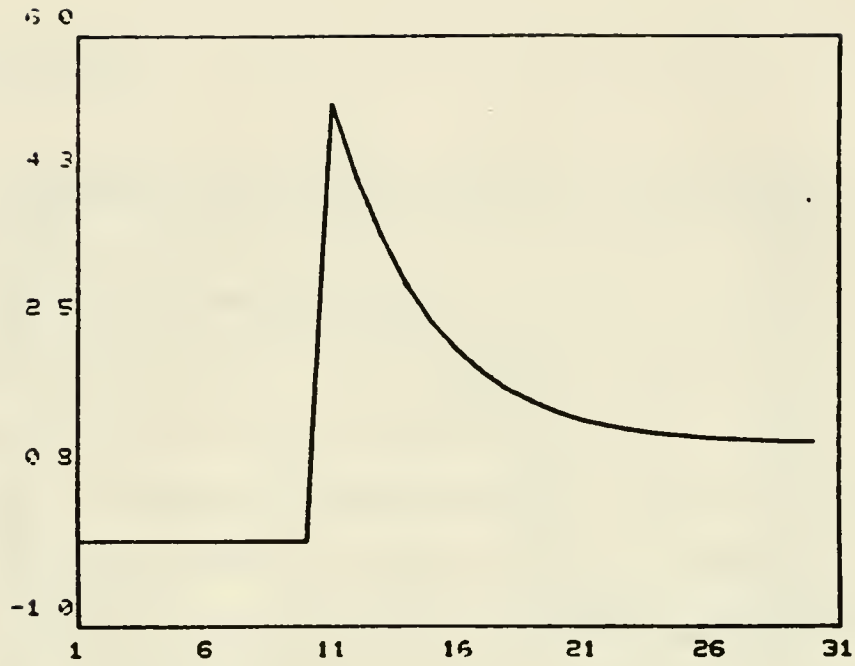(Innovation in Money)

Figure 3: Nominal Exchange Rate
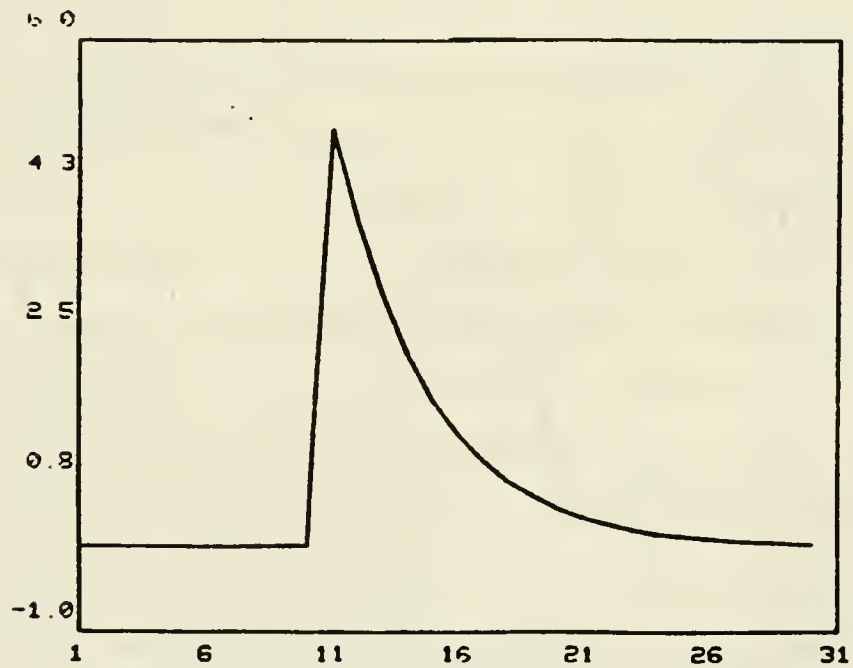(Innovation in Money)

Figure 4: Real Exchange Rate
(Innovation in Money)

exogenous variables = 0), a unit disturbance in the money process is observed. Figure 1 shows that the money stock does increase further after the shock, and eventually reaches a permanently higher level. This is due to the fact that, as discussed above, the data indicates the presence of nonstationarity of the money stock, and therefore we have estimated the money process, together with the foreign interest rate process, in the first differences. Figure 2 shows the response of the price level. As stressed above (Section 2), the price level reacts immediately to the innovation in the exogenous variable; after the shock, long run equilibrium is reached in a very smooth fashion, despite the sizeable swings in the stock of money. Figure 3 shows the exchange rate response. As predicted by the theory, the exchange rate is by far more volatile than the domestic price level. The simulations, which use the estimated parameters, do indeed provide support to the theory outlined above. At the time of the increase in the stock of money, the nominal exchange rate overshoots its steady state level as the theory, following Dornbusch would predict. The initial depreciation is four times larger than the steady state effect on the exchange rate. The large fluctuations in the nominal exchange rate generate big swings in the real exchange rate, as shown in figure 4.

Figures 5 to 8 illustrate the simulated effects of another financial shock: an increase in the U.S., treasury bills rate. As shown in figure 5, the estimated reaction of German monetary authorities implies that an increase in U.S. interest rates is followed by a large monetary contraction in Germany. This does not prevent a real depreciation of the exchange rate as shown in figure 8.

Figure 5: Foreign Interest Rate and Domestic Money
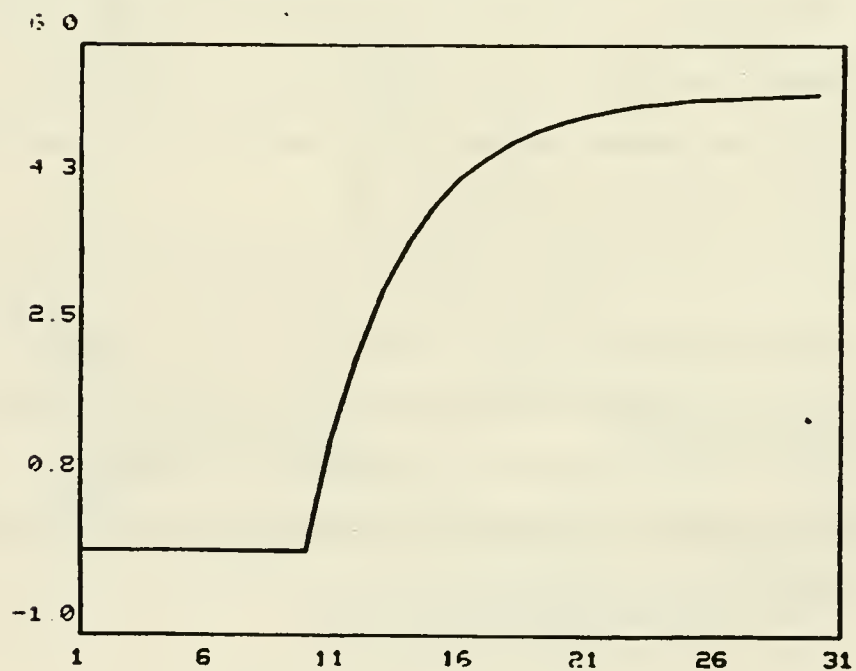(Innovation in Foreign Interest Rate)

Figure 6: Domestic Prices
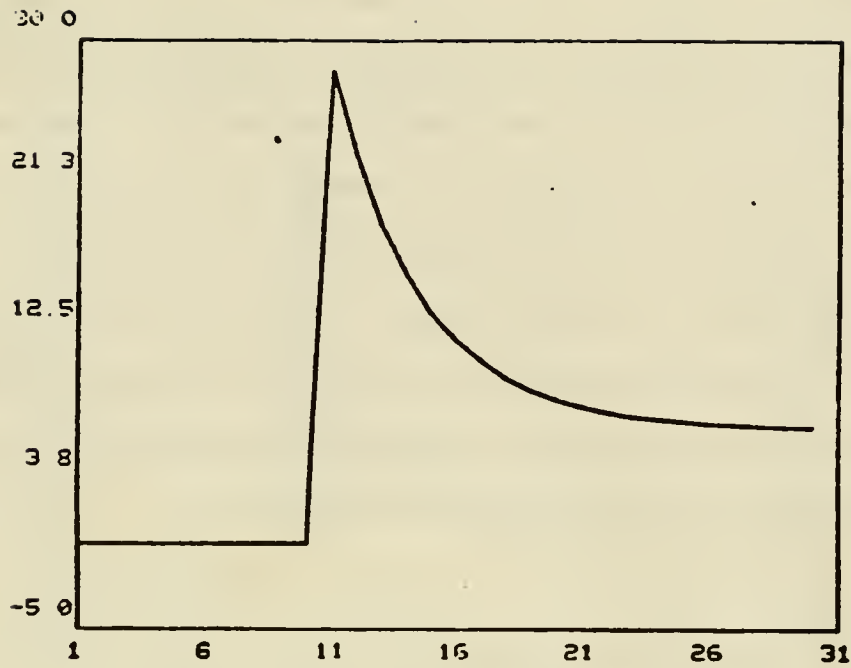(Innovation in Foreign Interest Rate)

Figure 7: Nominal Exchange Rate
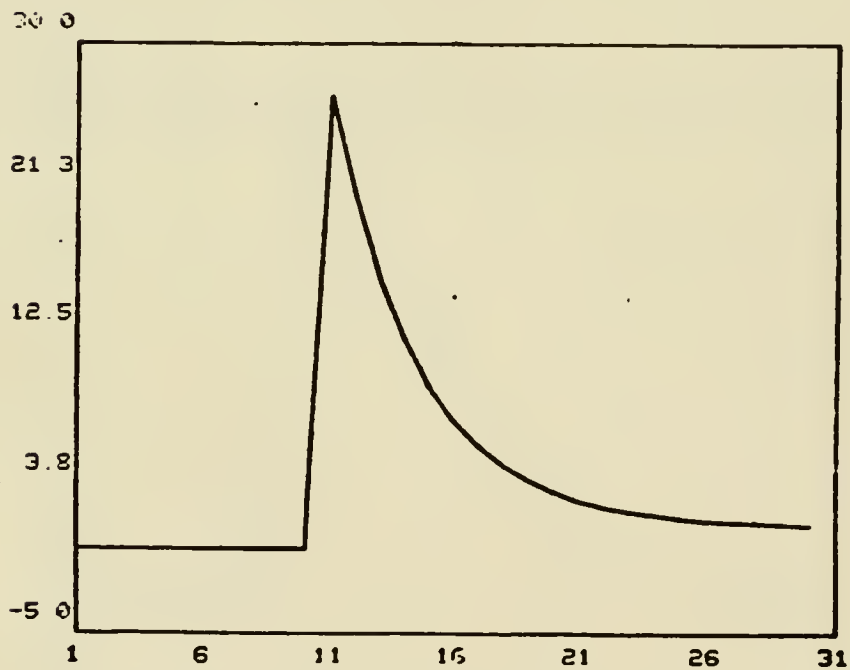(Innovation in Foreign Interest Rate)

Figure 8: Real Exchange Rate
(Innovation in Foreign Interest Rate)

Finally, figures 9 to 12 show the effects of a real disturbance, in the form of an increase in the real wage. Here again the exchange rate responses to the shock is much larger than the price level response, as the path of the real exchange rate demonstrates (figure 12). Some of the increase in costs is immediately passed into higher prices, which cause an excess demand for domestic money. For money market equilibrium, the domestic interest rate increases relative to the foreign interest rate, thus implying expectations of exchange rate depreciation, and an instantaneous appreciation of the exchange rate.
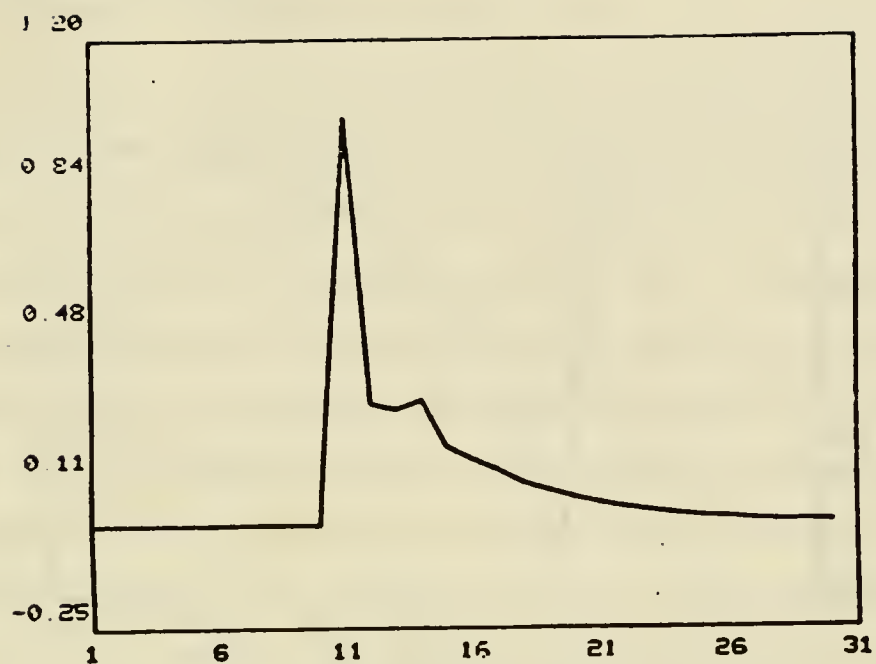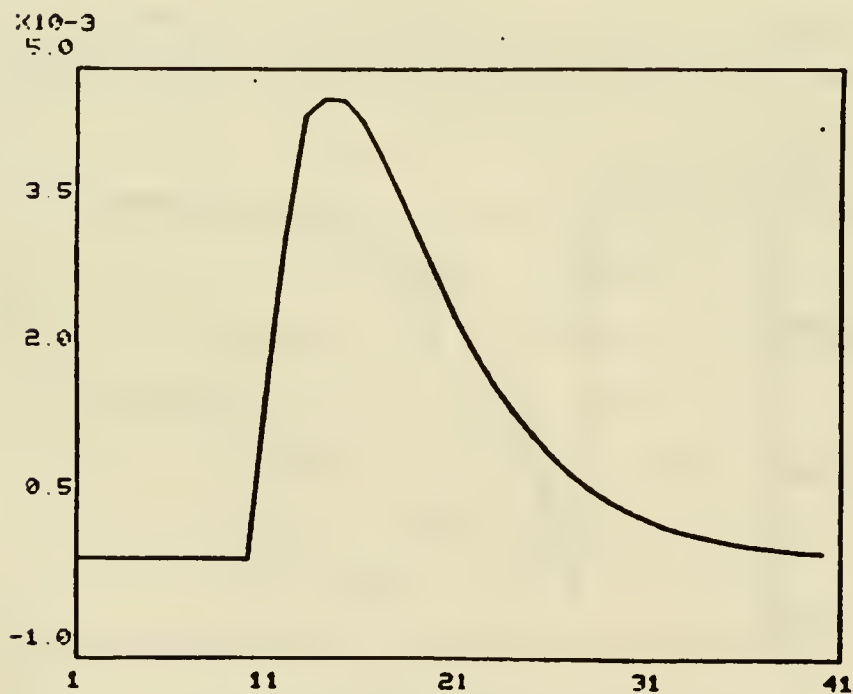
Figure 9: Real Wages

Figure 10: Domestic Prices
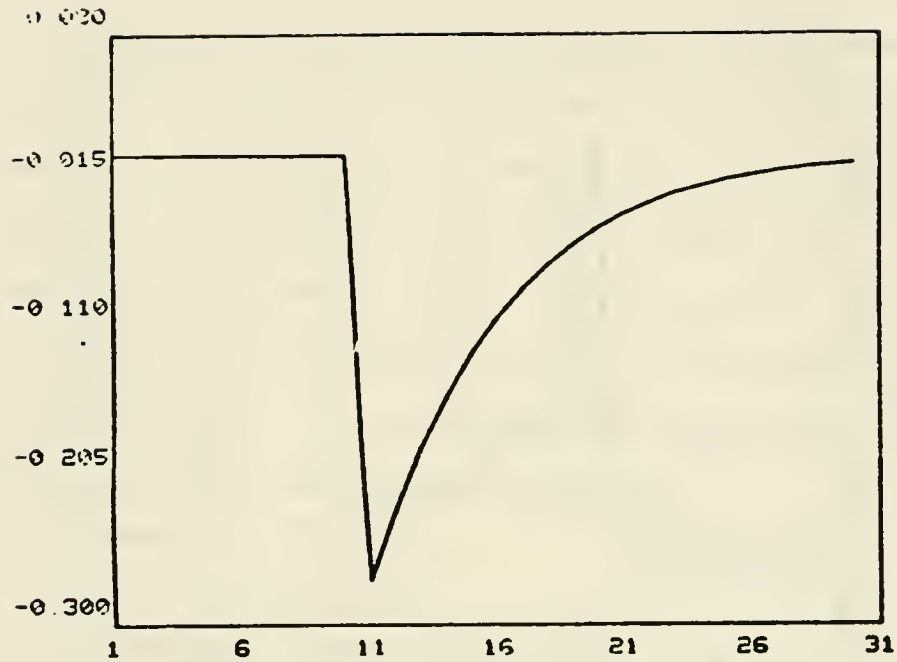(Innovation in Real Wages)

Figure 11: Nominal Exchange Rate
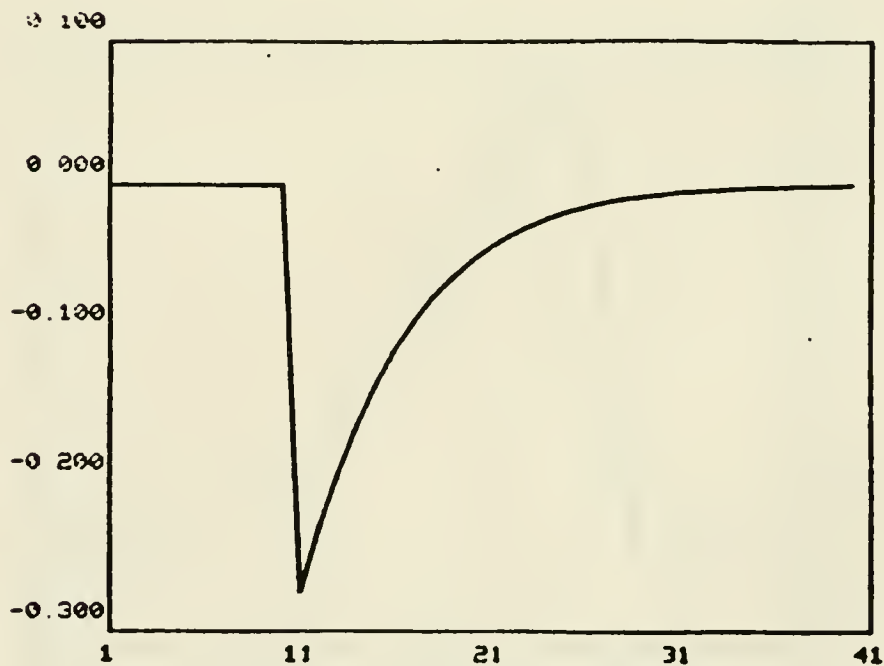(Innovation in Real Wages)

Figure 12: Real Exchange Rate
(Innovation in Real Wages)

5. Concluding Remarks

This paper has specified and estimated a model of sticky prices in an open economy, under the assumption of rational expectations. In the simulations, we have allowed the data to inform us as to the stochastic processes followed by exogenous variables. Such a model can shed light on important structural parameters like the relevance of overshooting. This ability is to some extent independent of whether the model forecasts well. Thus we disagree with the view that the poor forecasting performance illustrated by Meese and Rogoff (1983) completely invalidates structural estimation of exchange rate models. It is our opinion that a large class of exchange rate models, those which do not assume perfect wage and price flexibility and purchasing power parity, have so far received little attention from empirical researchers. For that reason, it is too early to make general statements about the empirical relevance of flexible exchange rate theories.

Our empirical analysis is partially successful. Estimates of the parameters of the model from the Euler equations do indicate that the empirical significance of costs in adjusting prices, the fundamental feature of our model, is considerable. However, the estimates of many parameters are very imprecise, and in a few cases, of the wrong sign. This latter phenomenon may be due to some simplifications on which our model is based, for analytical tractability: among these, the exogeneity of real wages, and the perfect substitutability hypothesis in assets markets are the most questionable.

Simulations of the model, using the parameter estimates obtained from Euler equations estimation, and the estimates of autoregressive

processes for the exogenous variables, show that the data yields predictions of the effects of disturbances that match the predictions of the theory. By far the largest proportion of short run real exchange rate volatility is accounted for by fluctuations in the nominal exchange rate: through this mechanism, nominal disturbances have important real effects.

APPENDIX 1:

The system of equations (14) has a unique convergent solution if and only if two eigenvalues of A have real parts whose absolute values are greater than one while the other eigenvalue's real part is smaller than one in absolute value. This is so because the system has only one initial condition namely p_{d0}. If there are more "stable roots there are infinitely many convergent solutions while on the other hand, the convergent solution if all roots are explosive may not satisfy the initial condition. The solution to the system (14) as long as these conditions are met uses the Jordan canonical form of A:

$$
\begin{bmatrix} A_{11} & A_{12} \\ (1\times1) & (1\times2) \\ \\ A_{21} & A_{22} \\ (2\times1) & (2\times2) \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} \\ (1\times1) & (1\times2) \\ \\ C_{21} & C_{22} \\ (2\times1) & (1\times2) \end{bmatrix}^{-1} \begin{bmatrix} J_1 & 0 \\ (1\times1) & \\ \\ 0 & J_2 \\ & (2\times2) \end{bmatrix} \begin{bmatrix} C_{11} & C_{12} \\ \\ C_{21} & C_{22} \end{bmatrix}
$$

$$
\text{where} \quad \begin{bmatrix} C_{11} & C_{12} \\ \\ C_{21} & C_{22} \end{bmatrix} \equiv C
$$

and J_1 is the stable root (real part less than 1), and J_2 is the diagonal matrix containing the unstable roots. A and the eigenvector matrix C are decomposed accordingly.

Following Blanchard and Kahn (1980):

$$
(16) \qquad \begin{bmatrix} p_{dt} \\ e_t \end{bmatrix} = -C_{22}^{-1}C_{21}p_{dt-1} - C_{22}^{-1} \sum_{i=0}^{\infty} J_2^{-(i+1)} C_{22}\gamma_{2t}z_{t+i}
$$

where γ_2 comes from the partition of B:

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ - & - & {}^-[\gamma_2] & - & - \end{bmatrix}$$

We will write equation (16) by expressing all the eigenvectors as functions of the eigenvalues and the elements of A. To do this premultiply both sides of (15) by C, normalize the eigenvectors, and solve for each of the elements of C. Substituting into (16), the price and exchange rate equations are:

$$P_{dt} = w_0 P_{dt-1} - (\frac{1}{J_{21}}) \sum_{i=1}^{8} w_{i1} [\sum_{k=0}^{\infty} (\frac{1}{J_{21}})^j {}_t z_{it+j}] - (\frac{1}{J_{22}}) \sum_{i=1}^{8} w_{i2} [\sum_{j=0}^{\infty} (\frac{1}{J_{22}})^j {}_t z_{it+j}]$$

$$e_t = \xi_0 P_{dt-1} - (\frac{1}{J_{21}}) \sum_{i=1}^{8} \xi_{i1} [\sum_{j=0}^{\infty} (\frac{1}{J_{21}})^j {}_t z_{it+j}] - (\frac{1}{J_{22}}) \sum_{i=1}^{8} \xi_{i2} [\sum_{j=0}^{\infty} (\frac{1}{J_{22}})^j {}_t z_{it+j}]$$

where:

$$w_0 = \frac{\phi_1}{\rho J_{22} J_{21}}$$

$$w_{11} = \frac{\phi_2(J_{21} - 1) + \alpha_2(\phi_1 - J_{21})}{\rho \phi_3(J_{22} - J_{21})}$$

$$w_{12} = - \frac{\phi_2(J_{22} - 1) + \alpha_2(\alpha_1 - J_{22})}{\rho \phi_3(J_{22} - J_{21})}$$

$$w_{21} = - \frac{(\phi_1 - J_{21})\alpha_2}{\rho \phi_3(J_{22} - J_{21})}$$

$$w_{22} = \frac{(\phi_1 - J_{22})\alpha_2}{\rho \phi_3(J_{22} - J_{21})}$$

$$w_{31} = - \frac{(\phi_1 - J_{21})\alpha_1}{\rho \phi_3(J_{22} - J_{21})}$$

$$w_{32} = \frac{(\phi_1 - J_{22})\alpha_1}{\rho \phi_3(J_{22} - J_{21})}$$

$$w_{41} = \frac{\phi_5 \phi_2 - \phi_6 (\phi_1 - J_{21})}{\rho \phi_3 (J_{22} - J_{21})}$$

$$w_{42} = \frac{\phi_5 \phi_2 - \phi_6 (\phi_1 - J_{22})}{\rho \phi_3 (J_{22} - J_{21})}$$

$$w_{51} = \frac{\phi_4 \phi_2 - (\phi_1 - J_{21}) \phi_7}{\rho \phi_3 (J_{22} - J_{21})}$$

$$w_{61} = \frac{-\phi_2}{\rho \phi_3 (J_{22} - J_{21})}$$

$$w_{62} = \frac{\phi_2}{\rho \phi_3 (J_{22} - J_{21})}$$

$$w_{71} = - \frac{(\phi_1 - J_{21})}{\rho \phi_3 (J_{22} - J_{21})}$$

$$w_{72} = \frac{(\phi_1 - J_{22})}{\rho \phi_3 (J_{22} - J_{21})}$$

$$w_{81} = \frac{\phi_2}{\rho \phi_3 (J_{22} - J_{21})}$$

$$w_{82} = \frac{- \phi_2}{\rho \phi_3 (J_{22} - J_{21})}$$

$$\xi_0 = - \frac{\phi_3}{\phi_2} \left[\frac{(\phi_1 - J_{21})(\phi_1 - J_{22})}{J_{21} - J_{22}} \right]$$

$$\xi_{11} = - \frac{(\phi_1 - J_{22})[\phi_2(J_{21} - 1) + \alpha_2(\phi_1 - J_{21})]}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{12} = \frac{(\phi_1 - J_{21})[\phi_2(J_{22} - 1) + \alpha_2(\phi_1 - J_{22})]}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{21} = \frac{(\phi_1 - J_{21})(\phi_1 - J_{22})\alpha_2}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{22} = -\frac{(\phi_1 - J_{21})(\phi_1 - J_{22})\alpha_2}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{31} = \frac{(\phi_1 - J_{21})(\phi_1 - J_{22})\alpha_1}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{32} = -\frac{(\phi_1 - J_{21})(\phi_1 - J_{22})\alpha_1}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{41} = -\frac{(\phi_1 - J_{22})[\phi_5\phi_2 - \phi_6(\phi_1 - J_{21})]}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{42} = \frac{(\phi_1 - J_{21})[\phi_5\phi_2 - \phi_6(\phi_1 - J_{22})]}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{51} = -\frac{(\phi_1 - J_{22})[\phi_2\phi_4 - \phi_7(\phi_1 - J_{21})}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{52} = \frac{(\phi_1 - J_{21})[\phi_2\phi_4 - \phi_7(\phi_1 - J_{22})]}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{61} = \frac{(\phi_1 - J_{22})}{J_{22} - J_{21}}$$

$$\xi_{62} = -\frac{\phi_1 - J_{21}}{J_{22} - J_{21}}$$

$$\xi_{71} = \frac{(\phi_1 - J_{21})(\phi_1 - J_{22})}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{72} = -\frac{(\phi_1 - J_{21})(\phi_1 - J_{22})}{\phi_2(J_{22} - J_{21})}$$

$$\xi_{81} = -\frac{(\phi_1 - J_{22})}{J_{22} - J_{21}}$$

$$\xi_{82} = \frac{\phi_1 - J_{21}}{J_{22} - J_{21}}$$

$$\phi_1 \equiv 1 + (\frac{1 - \lambda}{b})(1 - a(\gamma - d))$$

$$\phi_2 \equiv \beta(1 - \lambda)(\gamma - d) + (1 - \lambda)\alpha_1 + \alpha_2$$

$$\phi_3 \equiv c(1 + \beta\gamma)$$

$$\phi_4 \equiv \frac{ad - 1}{b}$$

$$\phi_5 \equiv \frac{af}{b}$$

$$\phi_6 \equiv \beta f$$

$$\phi_7 \equiv \beta d$$

Appendix 2: The Data

This paper presents an empirical analysis of the dollar mark exchange rate, but unlike earlier work, aggregates the rest of the world (for Germany) as a single dollar area.

Data for P_c^*, Q^* is computed using geometrically weighted averages of the individual series from the countries appearing on table A2.1, below.

Table A2.1

Country	Weight
U.S.A.	.157
France	.275
Italy	.184
Netherlands	.252
United Kingdom	.132

The weights are the average from 1974 to 1981 of the ratio of the value of imports plus exports of each country with Germany over the total trade of Germany with these countries. In 1981 the 5 countries in Table A2.1 represented 45 percent of the total trade of Germany. Individual countries' indices for P_c and q are aggregated using the respective exchange rates vis a vis the U.S. dollar.

Most of the data is obtained from the International Financial Statistics (IFS) tape. The index of wages in Germany and the index of intermediate inputs prices are computed using data from the Deutsche Bundesbank, Monthly Report, various statistical supplements.

The exchange rate is the price of a U.S. dollar in Deutsche marks, line rf in IFS (average over the month).

The domestic price level is line 63 of IFS, the index of wholesale prices.

P_C^* is computed aggregating the various countries indices of consumer prices, line 64 in IFS.

P_N^* is a weighted average of the IFS index of all commodities prices excluding oil, line 76a, and the index of the dollar price of oil for Saudi Arabia, line 76aa.

The weights are chosen from the geographical composition of Germany's imports, using data from the Deutsche Bundesbank Monthly Report. For the period 1974-1982 we computed the average share of imports from OPEC, in total imports less finished goods. The average value share of imports from OPEC is 22 percent.

i^* is the U.S. treasury bill rate, line 60c in IFS.

Q^* is the weighted average of industrial production indices, line 66c, expressed in dollar terms, by dividing each country's index by the real dollar exchange rate.

M is line 34 in IFS

K is the index of wage costs in industry, per man/hour, divided by the CPI. The former is from Bundesbank Monthly Bulletin, the latter is IFS line 64.

Theory requires that all series be realizations of stationary stochastic processes. All series have been demeaned and detrended by regressing the log of each against a constant, time and time squared. All seasonally unadjusted data has been adjusted by regressing each series on 11 monthly dummies.

FOOTNOTES

[1] The presence of real balances in the demand function for good i can be justified by making money yield utility. Then real money balances are a proxy for the marginal utility of income. In our model, since money demand is explicitly specified in equation (10),nothing would be lost if d were zero.

[2] Constant terms are not reported for simplicity.

[3] This approximation is spelled out in Rotemberg (1982(a)).

[4] This feature distinguishes this model from the traditional Dornbusch (1976) specification. There, the inflation rate depends only on the current value of m. This is due to Dornbusch's assumption that changes in m last foreever so that current m is the best forecast of future m. Driskill and Sheffrin (1981) have interpreted Dornbusch's continuous time model as saying that p_t is predetermined at t and thus doesn't depend on any current variables. For monthly data it is more plausible, and an equally correct interpretation of the continuous time model, to assume that p_t does indeed respond to m_t.

[5] Estimation of Euler equations for an exchange rate model with flexible prices is carried out in Glaessner (1982).

[6] The covariance matrix of the estimates is computed using the technique described in Eichenbaum, Hansen and Singleton (1984). This requires that one obtain the parameters of the vector moving average of order 1 followed by the products of instruments and residuals. To do this we first fit a vector autoregression of order 1 to the product of instruments and residuals. Then we explain these products by the lagged residuals of the vector autoregression. The coefficients of these lagged residuals are treated as the moving average parameters. This procedure is only valid asymptotically as long as the order of the vector autoregression grows with the number of observations in such a way that, asymptotically, its order is infinite. We use this method because the simpler procedure of Hansen (1982) does not always lead to a positive definite covariance matrix.

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